ABSTRACT A sample of the Crixás-Açu gneiss in Central Brazil contains protolith and metamorphic zircons, and two generations of metamorphic titanite. SHRIMP U-Pb data of these different mineral generations indicate the following temporal sequence: tonalitic magmatism at 2817 ± 9 Ma derived from an older source region (3050 to 2930 Ma zircon cores); Archaean metamorphism at 2772 ± 6 Ma (from zircon) with cooling to the blocking temperature of titanite (at 2711 ± 34 Ma); followed by Palaeoproterozoic metamorphism and weak fabric development at 2011 ± 15 Ma, and a possible Neoproterozoic metamorphism. The field relations and these age data indicate the polymetamorphic history of the area and demonstrate the value of in situ age determinations on well-characterized rocks.

Keywords: Archaean, Central Brazil, gneiss complexes, geochronology, titanite, SHRIMP

INTRODUCTION In the past decade, precise U-Pb geochronological techniques have markedly improved tectonic studies in greenstone belts, including SHRIMP analyses of zircons and other accessory minerals such as titanite. Zircon ages have generally been used to determine the crystallization ages of the rocks and the ages of inherited components, whereas titanite ages are commonly used to determine the ages of rocks or metamorphic events. Using SHRIMP analyses of titanite and zircon from a single sample of Crixás-Açu Gneiss, we have been able to resolve multiple metamorphic events in the history of the Caiamar Complex.

GEOLOGICAL SETTING The study area is a part of the Archaean terranes of the Tocantins Province (Almeida 1967, Fig. 1), central Brazil. It consists of low-grade greenstone belts and granite-gneiss complexes in a typical M-type dome-and-keel structure (sensu Marshak et al. 1997). Supracrustal rocks occur in three elongate, NS-trending belts named from West to East, the Crixás, Guarinos and Pilar de Goiás (Fig. 1). The Archaean block is partially overthrusted by Proterozoic metasedimentary sequences. Previous Sm-Nd, Rb-Sr, Ar/Ar, Pb/Pb, and U-Pb data (Tassinari and Montalvão 1980, Montalvão 1986, Arndt et al. 1989, Vargas 1992, Jost et al. 1993, Pulz 1995, Figure 1. Simplified geologic map of the Crixás Granite-Greenstone Belt Terrane.

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Fortes et al. (1997) suggest that the region developed under three main tectonic stages: (i) basin stage, including deformation and metamorphism of greenschist belts, followed by granitoid magmatism (3.0 Ga to 2.4 Ga); (ii) intrusion of basic dykes swarms and a dioritic intrusive stage (2.5 Ga to 2.3 Ga); (iii) overprinting during the Brasiliano/Pan-African Cycle (750 to 500 Ma).

A wide variety of textural, structural and compositional Archaean granitoids occur in the area. The Caíman Block (Danni and Ribeiro 1978) was mapped in detail and renamed by Jost et al. (1994) as a Complex, which contains three major units: the Crixás-Açu and Aguas-Claras Gneisses, and the Tocambará Tonalite which intrudes both gneisses (Fig. 1). The Complex also contains minor mafic dykes, pegmatoid veins, and migmatisites.

The typical Crixás-Açu Gneiss is light gray, fine to medium-grained, and has a metamorphic compositional banding given by the alternation of millimeter- to meter-wide melanocratic bands, and millimeter- to centimeter-wide leucocratic bands, both with granoblastic to lepidoblastic texture. The melanocratic bands have a tonalitic composition, and their major minerals are saussuritized oligoclase and quartz, with subordinate biotite and, locally, hornblende. Hornblende is commonly transformed into biotite and titanite. Zircon, apatite, epidote, titanite, muscovite, and locally mica chlorite, were hand-picked and mounted in epoxy (Dodson 1973), and their U-Th contents were used to correct for common Pb. A concordia diagram (Fig. 2) shows that the majority of the data are concordant. There is a distinct, major data population at 2011 ± 15 Ma (207Pb/206Pb age, 95% confidence limit, c2 = 0.69, n = 19, Group 2), with another possible cluster at 2711 ± 34 Ma (95% confidence limit, c2 = 0.17, n = 3, Group 1).

**DISCUSSION**

The oldest near-concordant zircon analyses from grain cores yield ages from 3050 Ma to 2930 Ma. These are interpreted as inherited cores rimmed by magmatic zircon. The spread of core ages may reflect multiple sources or partial resetting of old zircon. The 207Pb/206Pb ages show no correlation with 206Pb/238U and Th/U cannot be used to distinguish different zircon populations. The 2011 ± 9 Ma age of the youngest four concordant to nearly-concordant data give an age of 2011 ± 15 Ma (207Pb/206Pb age, 95% confidence limit, c2 = 0.69, n = 19, Group 2), with another possible cluster at 2711 ± 34 Ma (95% confidence limit, c2 = 0.17, n = 3, Group 1).

The titanite data cluster in three different, concordant to nearly-concordant sets in the concordia diagram (Fig. 2), i.e., ca. 2711 Ma, ca. 2011 Ma and a spread of from 2680 Ma to 2607 Ma. These data may be interpreted in many ways. First, does the 2011 Ma titanite age represent a resetting of the 2711 Ma population and, consequently, the spread of data from 2680 Ma to 2607 Ma represents a diffusive Pb-loss/overprint or the 2011 Ma, on the other hand, do the 2711 Ma and the 2011 Ma ages represent two different titanite generations/growth stages?

The absence of morphological differences between both populations, the concordant spread about 2.6 Ga, and the Th/U ratios and U-Th contents of the younger population that varies within the range of the oldest population suggest differential resetting of the younger population (ca. 2711 Ma). However, the absolute lack of data between 2600 Ma and 2237 Ma suggests there is no Pb-loss chord. The Th/U ratios may represent only the Th and U contents available in the rock.

There is also the possibility that small parts of the ca. 2711 Ma relics grains, could be annealed by the ca. 2011 Ma event, a process suggested by Zhang and Schöfer (1996), Pidgeon et al. (1996), and Cliff and Cohen (1980). Although the titanite population was investigated by backscatter electron images, no distinct cores or foreign fragments were found.

The closure temperature of titanite, defined as the temperature of the system at the time given by its apparent age (Dodson 1973), is around 500°C (Cherniak 1991, Mezger et al. 1993, Mezger et al. 1991, Cliff and Cohen 1980, p.ex.). Titanite grains of approximately 1cm size have closure temperature above 630°C, and of
0.05 cm grain-size it is between 500°C and 550°C (Mezger et al. 1991, 1993). Cherniak (1993) points out that cores of 0.5 cm titanite crystals have a minimum closure temperature of 780°C, that drops to 650°C in 0.005 cm crystals. There seems to be a consensus that smaller grains have a lower closure temperature.

The studied titanite grains are fragments of crystals between 0.005 cm and 0.01 cm, compatible to a minimum closure temperature of 500°C. If the two generations differ in grain-size, then they might have different closure temperatures. However, from thin section examination, the coarser titanite is intergrown with quartz and plagioclase and may be magmatic or metamorphic and formed during the gneissic banding, whereas the smaller titanite is in association with the later biotite-rich crosscutting fabric. Thus, it is suggested that the older population (ca. 2711 Ma) formed under higher closure temperature than the younger one (ca. 2011 Ma), and the Palaeoproterozoic metamorphism did not completely reset the former.

However, the absence of a range of titanite ages between 2.7 and 2.0 Ga, reflecting different grain sizes, would argue against this interpretation. The alternative is that the new growth of 2.0 Ga titanite occurred below the ~500°C blocking temperature of the 2.77-Ga titanite, allowing the earlier titanite to preserve its age. Thus, the zircon age of 2772 ± 6 Ma is interpreted as the age of an Archaean metamorphism whereas the titanite age of 2711 ± 34 Ma is considered as due to further metamorphic cooling. Therefore, the titanite with an age of 2011 ± 15 Ma is interpreted as representing a Palaeoproterozoic metamorphism and deformation.

CONCLUSIONS

The U-Pb SHRIMP data of part of the granitoids of the studied area indicate that the exposed Archaean terranes hide an older crust, as suggested by inherited zircon cores (3.05 Ga to 2.93 Ga). The magmatic age of the Crixás-Açu Gneisses (2817 ± 9 Ma) and the age of metakomatiites of the Crixás Belt (2825 ± 98 Ma; Arndt et al. 1989), added to their mutual field relationships leads to the interpretation that the gneisses are part of the M-type dome-and-keel structure evolution. The prior tonalitic intrusion underwent amphibolite facies metamorphism during the Archean, as deduced from the inferred metamorphic zircon (2772 ± 6 Ma). The oldest titanite population indicates that metamorphic cooling took place at ca. 2711 ± 34 Ma, and the youngest reflects a Palaeoproterozoic 2011 ± 15 Ma event materialized in the faint crosscutting fabric. The lack of resetting of the older population suggests that the youngest titanite grew below the minimum titanite U–Pb blocking temperature of 500°C (Cherniak 1993, Mezger et al. 1993, Mezger et al. 1991, Cliff and Cohen 1980). The example of the Crixás-Açu Gneisses is, on the other hand, a first known case where polymetamorphic rocks may contain titanite of more than one age if later events took place at lower temperatures.
### Table 1 - Isotopic data from sample 98-38 (zircons), Crixás-Açú Gneiss, Caiamar Complex

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### Table 2 - Isotopic data from sample 98-77 (titanites), Crixás-Açú Gneiss, Caiamar Complex

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* = used for age calculation.
Errors in column 206 Pb*206 Pb are quoted as significant figures only. All errors ± 1σ. All data are 204 corrected.

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### Notes:
- All data are 204 corrected.
- Errors in column 206 Pb*206 Pb are quoted as significant figures only.
- All errors ± 1σ.
- All data are 204 corrected.

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